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Robotic Operator Performance in Simulated Reconnaissance Missions

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ARL-TR-3628 **October 2005**

NOTICES

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Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5425

ARL-TR-3628 **October 2005**

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*: October 2005	2. REPORT TYPE: Final
3. DATES COVERED (From - To): June 2004 to June 2005	
4. TITLE AND SUBTITLE: Robotic Operator Performance in Simulated Reconnaissance Missions	5a. CONTRACT NUMBER:
	5b. GRANT NUMBER:
	5c. PROGRAM ELEMENT NUMBER:
6. AUTHOR(S): Jessie Y.C. Chen (ARL); Paula J. Durlach (ARI); Jared A. Sloan (USMA); Laticia D. Bowens (UCF)	5d. PROJECT NUMBER: 62716AH70
	5e. TASK NUMBER:
	5f. WORK UNIT NUMBER:
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES): U.S. Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, MD 21005-5425	8. PERFORMING ORGANIZATION REPORT NUMBER: ARL-TR-3628
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES):	10. SPONSOR/MONITOR'S ACRONYM(S):
	11. SPONSOR/MONITOR'S REPORT NUMBER(S

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The goal of this research was to examine how robotic operators' performance differed, depending on the type and number of assets available. Operator strategies for using multiple robotic vehicles were examined. We also investigated how sensor feed degradations affected operators' performance and perceived workload. The results suggest that giving robotic operators additional assets may not be beneficial. Target detection was most poor for the teleoperated vehicle (Teleop), probably because of the demands of remote driving. Slowing sensor-fed video frame rate or the imposition of a short response latency of 250 ms between Teleop control and reaction failed to affect operators' performance significantly.

15. SUBJECT TERMS

frame rate; human-robot interaction; latency; operator control unit; simulation; span of control; target detection; unmanned vehicle

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	SAR	60	Jessie Y.C. Chen
					19b. TELEPHONE NUMBER (*Include area code*): 407-384-5435

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

The authors wish to thank Mr. Michael J. Barnes of the U.S. Army Research Laboratory's Human Research and Engineering Directorate for his support and guidance throughout the process of this research project. Mr. Barnes is the co-manager of the Technology for Human-Robot Interaction (HRI) Soldier Robot Teaming Army Technology Objective and provided much valuable advice about important HRI issues to us. The authors also wish to thank Mr. Henry Marshall of the Research, Development, and Engineering Command, Simulation and Training Technology Center, for his support. Without Mr. Marshall's simulator equipment, this work would not have been possible. Mr. Gary Green of the University of Central Florida, Institute for Simulation and Training, and his group were an integral part of this research effort. Their excellent work made our data collection and extraction process a very smooth one. We would also like to acknowledge LTC Mike Sanders for his contributions to our project. LTC Sanders helped us train our participants to use the simulator. His expertise and guidance were greatly appreciated. Finally, we would like to thank our reviewers for their helpful comments.

1. Introduction

1.1 Purpose

The goal of this research is to examine the ways in which human operators interact with unmanned ground vehicles (UGVs) and unmanned aerial vehicles (UAVs). One specific objective is to evaluate how many robotic vehicles an operator can effectively manage at one time and how the operator's performance is affected by the quality of video image from the robotic vehicles. The understanding of the robotic operator's span of control is key to successful operation of robotic assets that are an important part of the U.S. Army's current force and will be an essential part in the Army's future force (Kamsickas, 2003).

1.2 Background

The robotic operator's span of control is one of the most important issues in robotic operational environments. In recent years, research has been conducted to investigate the robotic operator's performance when more than one unmanned asset is employed, compared to when only one is used (Dixon, Wickens, & Chang, 2003; Rehfeld, Jentsch, Curtis, & Fincannon, 2005). Dixon et al. examined pilots' performance in simulated military reconnaissance missions using UAV(s). They found that pilots actually detected fewer targets with two UAVs than with a single UAV. Rehfeld et al. examined cost benefits of various human-robot interaction (HRI) teaming concepts by conducting a laboratory experiment in a scale military operations in urban terrain setting. They compared one versus two UGVs and found that the additional UGV did not enhance the target detection performance of the operator(s). In fact, in difficult scenarios, the single operators actually performed worse with two robots than with one robot.

Generally speaking, the robotic operator's workload tends to be higher when s/he has to teleoperate a robot or manually intervene when the robot's autonomous operation encounters problems, compared to managing autonomous robots (Dixon et al., 2003; Schipani, 2003). Dixon et al. demonstrated that automation appeared to benefit UAV pilots' target detection performance. Similarly, Allender and Luck (2005) reported that robotic operators' situational awareness (SA) was better when the small UGV had a higher level of automation. According to Fong, Thorpe, and Baur (2003), teleoperation tends to be challenging because operator performance is "limited by the operator's motor skills and his ability to maintain situational awareness…difficulty building mental models of remote environments…distance estimation and obstacle detection can also be difficult" (p. 699).

In addition to control modality, the communication channel between the human operator and the robot is essential for effective perception of the remote environment. Factors such as distance, obstacles, or electronic jamming may pose challenges for maintaining sufficient signal strength

(French, Ghirardelli, & Swoboda, 2003). As a result, the quality of video "feeds" that a teleoperator relies on for remote perception may be degraded, and the operator's performance in distance and size estimation may be compromised (Van Erp & Padmos, 2003). The following two sections briefly review past research on effects of slow frame rate (FR) and latency on human performance.

1.2.1 Frame Rate

Common forms of video degradation caused by low bandwidth include reduced FR (frames per second), reduced resolution of the display (pixels per frame), and a lower gray scale (number of levels of brightness or bits per frame) (Rastogi, 1996). Piantanida, Boman, and Gille (1993) found that participants' depth and egomotion perception degraded when FRs dropped. Similarly, Darken, Kempster, and Peterson (2001) demonstrated that people had difficulty maintaining spatial orientation in a remote environment with a reduced bandwidth. The participants also had great difficulty in identifying objects in the remote environment. For applications in virtual environments, many researchers recommend 10 Hz to be the minimum FR to avoid performance degradation (Watson, Walker, Ribarsky, & Spaulding, 1998). Van Erp and Padmos (2003) suggest that speed and motion perception may be degraded if image update rate is below 10 Hz. Massimino and Sheridan (1994) demonstrated that teleoperation was significantly affected with a rate of five to six frames/second and became almost impossible to perform when the FR dropped below three frames/second. According to Van Erp and Padmos (2003), lowering the image update rate may affect speed estimation and braking. French et al. (2003) showed that reduced FRs (e.g., two or four frames/second) affected the teleoperator's performance in navigation duration (time to complete the navigation course) and perceived workload. It was worth noting that no significant differences were found among different FRs (i.e., 2, 4, 8, and 16 fps) for navigation error, target identification (ID), and SA. The authors, however, recommended that no fewer than eight frames per second should be employed for teleoperating UGVs. It appears that increasing the FR to higher than 8 Hz might not greatly enhance indirect driving performance. For example, in a study on teleoperation of ground vehicles, McGovern (1991) did not find driving performance degradation when image update rates were lowered from 30 to 7.5 Hz. According to Kolasinski (1995), slow FRs, which are usually associated with visual lag, may cause perceived simulator sickness. However, the effect of slow FR on simulator sickness tends to be indirect and can vary widely, based on scene complexity.

1.2.2 Latency

Another video-related factor that might degrade the robotic operator's performance is time delay. Time delay (i.e., latency, end-to-end latency, or lag) refers to the delay between input action and (visible) output response and is usually caused by the transmission of information across a communications network (MacKenzie & Ware, 1993; Fong et al., 2003). Studies of human performance in virtual environments show that people are generally able to detect latency as low

as 10 to 20 ms (Ellis, Mania, Adelstein, & Hill, 2004). Sheridan and Ferrell (1963) conducted one of the earliest experiments on the effects of time delay on teleoperation. They observed that time delay had a profound impact on the teleoperator's performance, and the resulting movement time increases were well in excess of the amount of delay. Based on this and other experimental results, Sheridan (2002) recommended that supervisory control and predictor displays be used to ameliorate the negative impact of time delays on teleoperation. Generally, when system latency is more than about 1 second, operators begin to switch their control strategy to "move and wait" instead of continuous command to compensate for the delay (Lane et al., 2002).

Research has shown that time delays of less than 1 second can also degrade human performance in interactive systems. In a simulated driving task, the driver's vehicle control was found to be significantly degraded by a latency of 170 ms (Frank, Casali, & Wierville, 1988). According to Held, Efstathiou, and Greene (1966), latency as short as 300 ms would make the teleoperator decouple his or her commands from the robotic system's response. Warrick (as cited in Lane et al., 2002) also showed that participants' compensatory pursuit tracking performance degraded with a latency of 320 ms. Lane et al. (2002), on the other hand, did not find any performance degradation in a three-dimensional tracking task until the latency was more than 1 second, although the authors reported that it took the participants significantly longer to complete a position (i.e., extraction and insertion) task when the latency was more than 500 ms. In a study of target acquisition (TA) using the classic Fitts' law paradigm, MacKenzie and Ware (1993) demonstrated that movement times increased by 64% and error rates increased by 214% when latency was increased from 8.3 ms to 225 ms. A model of modified Fitts' law (with latency and difficulty in having a multiplicative relationship) was proposed, based on the experimental results. In another study of latency effects on performance of grasp and placement tasks, Watson et al. (1998) found that when the standard deviation of latency was above 82 ms, performance degraded (especially for the placement task, which required more frequent visual feedback). It was suggested that a short variable lag could be more detrimental than a longer, fixed one (Lane et al., 2002). Over-actuation (e.g., over-steering and repeated command issuing) is also common when system delay is unpredictable (Kamsickas, 2003; Malcolm & Lim, 2003). Additionally, time delay has been associated with motion/cyber sickness, which can be caused by cue conflict (i.e., discrepancy between visual and vestibular systems) (Stanney, Mourant, & Kennedy, 1998; Kolasinski, 1995).

1.3 Current Study

The goal of this research was to examine the ways in which human operators behave when they are controlling robotic platforms. The operator's task was to conduct route reconnaissance missions in a simulated environment. During each mission, the operator employed one or three robots to detect enemy targets along a designated route. Each participant conducted four missions, three with a different robotic asset each, and a final mission with all three robotic assets at their disposal. Two of the assets were semi-autonomous. For these, operators assigned a set of way-points and the robots then traveled the route automatically, unless the operator

intervened to alter their behavior. As the robot traveled, the operator manipulated the sensors searching for targets. The semi-autonomous robots were a UAV and a UGV. The third robot was a ground vehicle requiring Teleop; in other words, the operator had to remotely drive this vehicle while manipulating its sensors to search for targets at the same time. All vehicles were simulated to be equipped with camera sensors, which could be panned/zoomed and could send streaming video back to the operator control station (OCS). As previously discussed, Dixon et al. (2003) demonstrated that the pilots' target search performance improved when the UAV was on auto-pilot, compared to when they had to manually pilot the UAV. In the current study, target detection for a semi-autonomous versus manually piloted UGV was evaluated.

The current study also examined the issue of operator's span of control of robotic assets. The understanding of an operator's span of control is key to successful employment of robotic assets, which are increasingly being deployed for military operations (Kamsickas, 2003; Barnes, Cosenzo, Mitchell, & Chen, 2005). One of our objectives was to examine the initial strategies used when a single operator is assigned the control of multiple heterogeneous robotic vehicles. Superficially, more assets should facilitate mission performance since operators will have access to different perspectives of the environment; however, the challenge of vehicle coordination and the need to monitor multiple sensor feeds might undermine the benefits of greater sensor coverage. In addition, control of multiple robotic vehicles might require additional training beyond the training given for the operation of each individual vehicle. Dixon et al. (2003) and Rehfeld et al. (2005) reported that participants did not perform better with two robots than with a single robot and actually performed worse in more difficult conditions. In the multiple asset condition of the current study, in contrast with the Dixon et al. and Rehfeld et al. studies, we used three heterogeneous unmanned vehicles (UV) instead of multiple homogeneous platforms.

Another aim was to investigate whether individual differences in spatial ability might impact the performance. Spatial ability is the ability to navigate or manipulate objects in a two- or three-dimensional space (Eliot, 1984). Gugerty (2004) found that UAV operators report difficulty in maintaining spatial orientation. Lathan and Tracey (2002) showed that people with higher spatial ability performed better in a teleoperation task through a maze. They finished their tasks faster and had fewer errors.

Finally, we sought to investigate whether operator performance would be affected by temporal aspects of the video image transmitted back from the robotic vehicles. In a real situation, communication constraints might affect the latency between robotic control input and observable changes in the sensor feed or might affect the FR at which the sensor feed can be displayed (Rastogi, 1996). This might have consequences for maintenance of SA, distance estimation, and target or obstacle detection (Darken et al., 2001; Fong et al., 2003; Van Erp & Padmos, 2003).

For one group of participants (Group Latency), a latency was imposed between control input and observable responses of the Teleop vehicle. Such a time delay is a realistic potential consequence of the need to transmit information between the OCS and the robotic platform. In

our experiment, we employed a fixed latency of 250 ms, based on the findings from the literature that latencies between 225 and 300 ms would degrade human performance in tasks such as teleoperation, tracking, and TA (MacKenzie & Ware, 1993; Held et al., 1966; Warrick, as cited in Lane et al., 2002).

For the second group (Group Frame), no latency was imposed between control input and responses of the Teleop vehicle; however, this group had a different manipulation. For Group Frame, the FR of the sensor video sent to the OCS from all the robotic platforms decreased as a function of the distance between the robotic platform and the OCS. Consequently, at the beginning of each mission, the FR was normal (i.e., 25 Hz) but decreased over the mission as the robot traveled away from the OCS. FR at the end of a mission was approximately 5 Hz.

In order to isolate the effect of the latency manipulation, we compared the Teleop performance data of Groups Latency and Frame from a time period when the FR for Group Frame was normal. This was the first quarter of the teleop missions. In order to isolate the effect of the FR manipulation, we compared the performance results during the first quarter (normal FR) and the last quarter (decreased FR). The FR analysis included the performance results of missions with the semi-autonomous platforms only so as not to contaminate the analysis with the effects of the latency manipulation (which affected only the Teleop robot). An effect of FR should appear as a Group × Quarter interaction, with the performance of the two groups being similar during the first quarter but different during the last quarter. The four experimental sessions are presented in table 1.

Table 1. Type and number of robotic assets and video degradation conditions.

	Robot Condition			
Video Cond.	**Autonomous UAV**	**Autonomous UGV**	**Teleop (UGV)**	**Mixed**
Frame	1 UAV with slow FR			
		1 UGV with slow FR		
			1 teleop with slow FR	
				1 UAV with slow FR 1 UGV with slow FR 1 teleop with slow FR
Latency	1 UAV with normal video			
		1 UGV with normal video		
			1 teleop with latency	
				1 UAV with normal video 1 UGV with normal video 1 teleop with latency

We were also interested in examining if the FR and latency manipulations would induce any simulator sickness symptoms and how gender differences would interact with these factors. According to the literature, slow FR and time lag may lead to increased simulator sickness, and females may be more susceptible (Pausch, Crea, & Conway, 1992). Simulator sickness susceptibility also tends to be a function of the operator's degree of control (Kolasinski, 1995). It was observed in simulation studies that participants who generated input themselves tended to report less sickness (Pausch et al., 1992). In our experiment, although both the UGV and the Teleop were ground vehicles, participants could anticipate the movement of the Teleop (although there was a slight delay between the input and the movement) better than they could with the semi-autonomous UGV. The conflict between the visual cue and the participants' own physical state (basically stationary) when they controlled the UGV might result in more severe sickness. It was also reported in the literature that altitude tends to be one of the strongest contributors to sickness (Kennedy, Berbaum, & Smith, 1993). Lower altitudes tend to induce more severe sickness because of the greater visual flow cues indicating movement (Kolasinski, 1995). In our study, both the UAV and the UGV were semi-autonomous but one was aerial while the other was ground vehicle. We were interested in ascertaining if the UGV would induce more severe sickness because of its lower altitude and greater visual flow.

In summary, the independent variables examined in this current study were number of robotic assets (1 versus 3), type of robotic assets (UAV, UGV, and Teleop), and forms of video degradation (slow frame rate and latency). It was expected that operators would not perform better with three robots in target detection tasks. It was also expected that operators would perform better with the UAV and UGV than with the Teleop. Both forms of video degradation were expected to affect operators' TA performance. Participants with higher spatial ability were expected to outperform those with lower spatial ability, in terms of both speed and accuracy.

2. Method

2.1 Participants

Thirty students (11 females and 19 males; 27 undergraduates and 3 graduate students) were recruited from the University of Central Florida and participated in the study. The ages of the participants ranged from 18 to 33 (female: $M = 21$, $SD = 4.07$; male: $M = 19$, $SD = 1.9$). Of the 30 participants, 25 self reported being at least good with computers, 4 reported as excellent, and 1 expert. As for video game experiences, 27 participants reported playing at least some video games. Participants were paid $50 or given class credit for their participation in the experiment.

2.2 Apparatus

2.2.1 Simulator

The experiment was conducted with the Embedded Combined Arms Team Training and Mission Rehearsal (ECATT-MR) test bed at the Simulation and Training Technology Center of Research, Engineering, and Development Command (RDECOM) in Orlando, Florida. The operator control display for the ECATT-MR is illustrated in figure 1. The test bed was equipped with a steering wheel and gas and break pedals for control of the teleoperated vehicle. Mechanical buttons on the steering device provided for control of the targeting and weapons systems of the teleoperated vehicle (weapons were not used in this study, however). The OneSAF (Semi-Automated Forces) test bed was used to provide the simulated environments and the computer-generated forces.

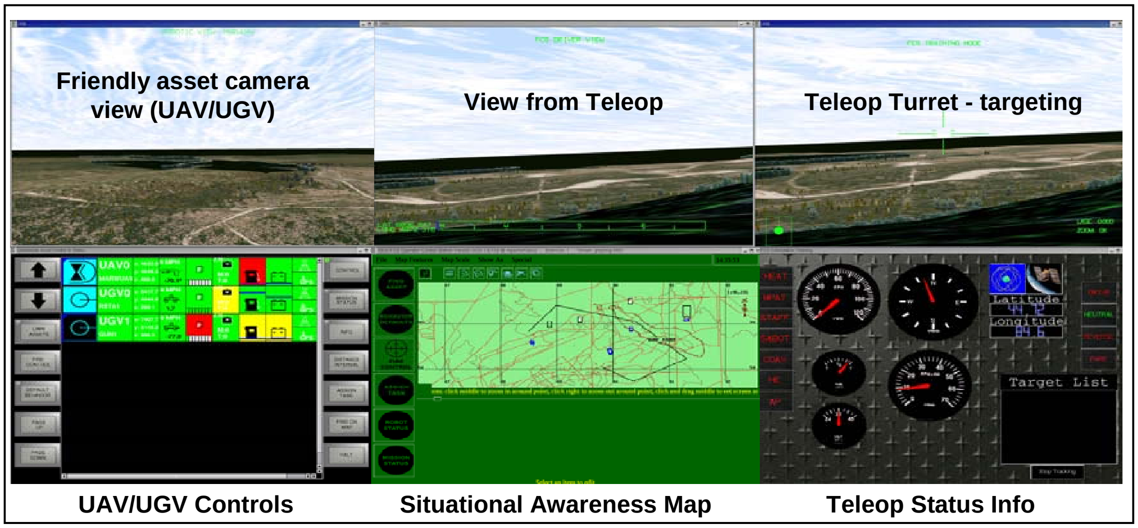

Figure 1. User interface of ECATT-MR test bed.

2.2.1.1 Tele-operating the Robotic Vehicle

Driving the Teleop vehicle was similar to driving a car, although the operator had to first select the “drive” function on the touch screen and then start driving using the pedal and the steering yoke, which also had several buttons for controlling the weapons and targeting system of the robotic asset (figure 2). When a target appeared in the robotic vehicle’s field of view, it also appeared as a string of letters and numbers on the “target list” (each target’s ID was unique) on the lower right portion of the Teleop status display. Once a target had been located, the operator first drove the Teleop within range, and then s/he could rotate the main gun 360 degrees and raise and lower it to adjust the turret view (with a crosshair in the center) by controlling the steering yoke. The right palm grip, however, needed to be depressed in order for the operator to rotate or raise/lower the gun. Once the target was inside the gun’s crosshairs, the operator could press the “lase” button (on the right handle of the steering console) to determine the range of the unit, which was shown on the Teleop turret display (top right screen).

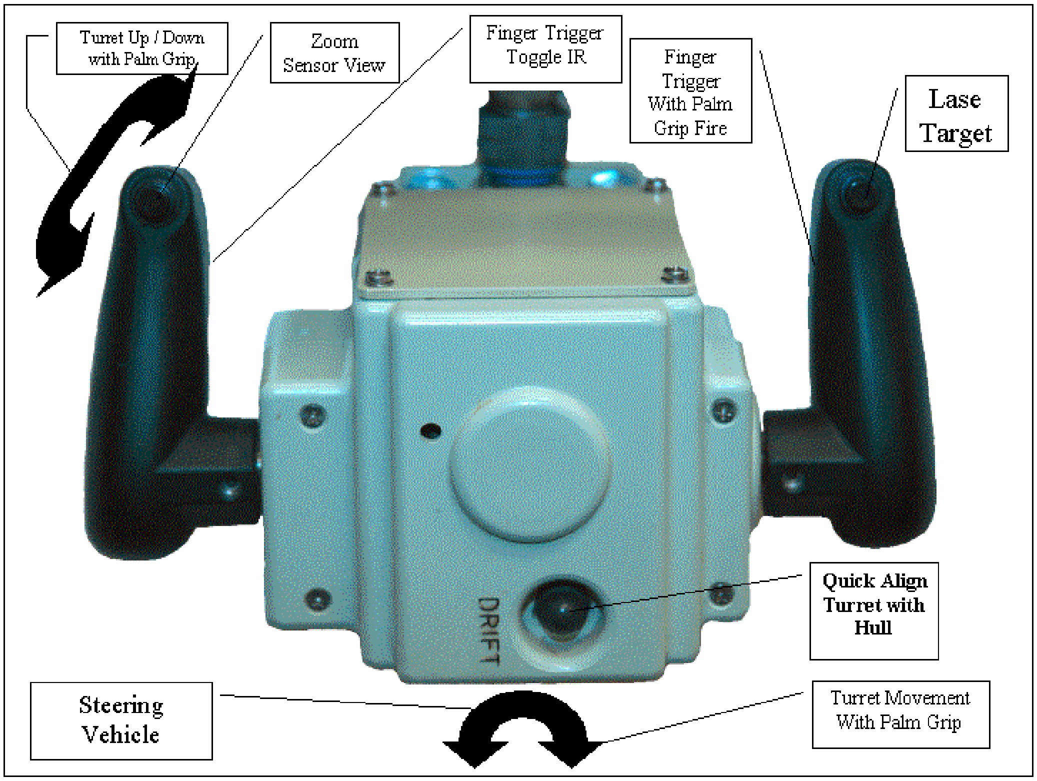

Figure 2. Diagram of yoke control buttons (from unpublished ECATT-MR manual prepared by RDECOM STTC, 2004).

2.2.1.2 Controlling the Semi-autonomous Robotic Vehicles

The operator used the UV status panel for managing the UAV and the UGV (figure 3). The "lase" function was under "engagement" and the operator could tilt and pan the camera sensor for each asset by selecting the "sensor view" button. The operator selected the "assign task" button, for example, to move an asset or order the UAV to hover. Typically, at the start of a scenario, the operator placed way points on the SA map (lower center screen) using its Point Editor and then "assign task" to send the robot into its reconnaissance mission. Both the UAV and the UGV traveled at 20 kph, and the default altitude for the UAV was 100 m. When the operator detected a target, s/he first halted the robot and adjusted the sensor view by pressing the appropriate buttons (e.g., left, right, down, up, etc.) so the crosshair was on the target before firing the laser at the target by pressing the "lase" button. A detailed SA map is presented in figure 4.

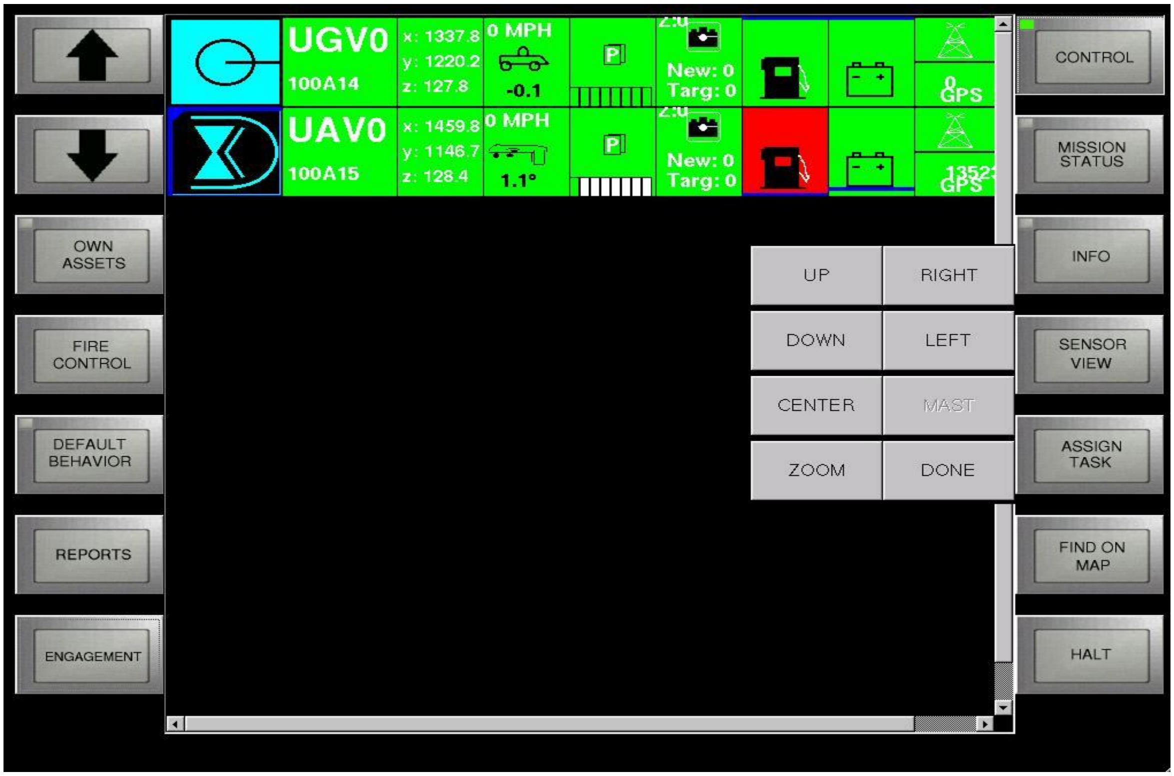

Figure 3. UV status display - sensor view.

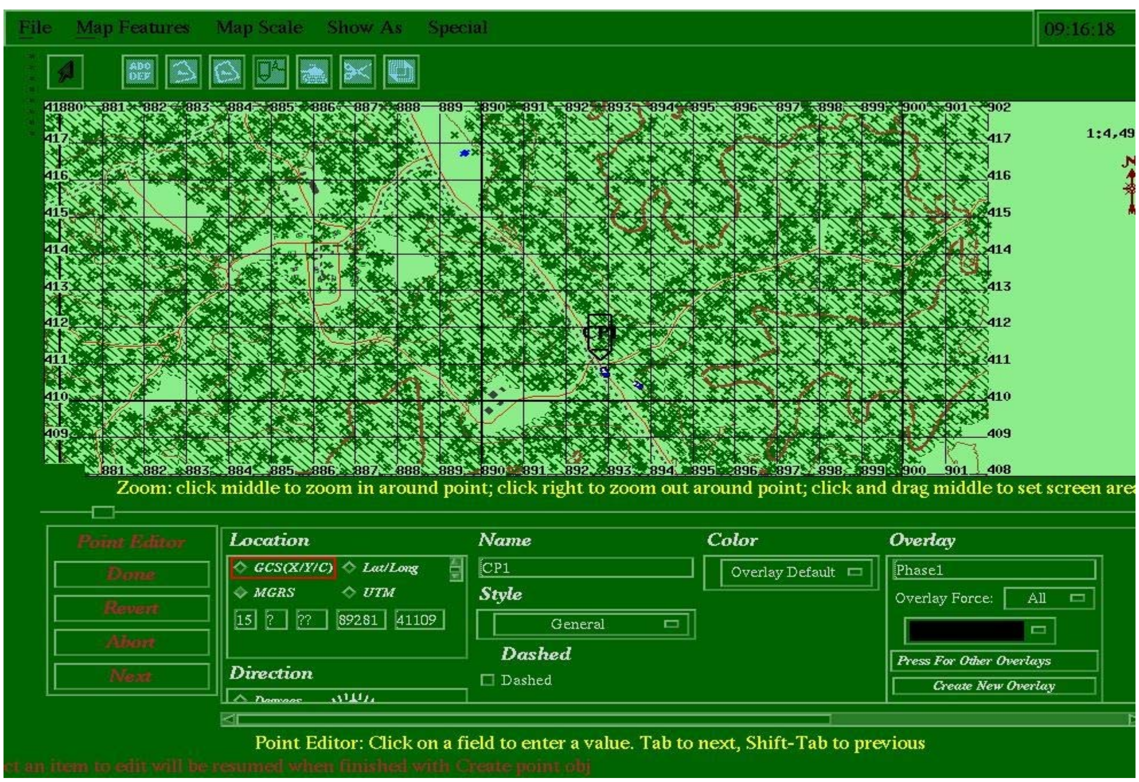

Figure 4. SA map display (MD).

2.2.2 Questionnaires

The Cube Comparison Test (Educational Testing Service, 2005) was administered to assess participants' spatial ability. The Cube Comparison Test requires participants to compare, in 3 minutes, 21 pairs of six-sided cubes and determine if the rotated cubes are the same or different.

Appendix A presents the demographics questionnaire administered at the beginning of the training session.

Perceived workload was measured by the National Aeronautics and Space Administration's task load index (NASA-TLX) questionnaire (appendix B). The NASA-TLX is a self-reported questionnaire of perceived demands in nine areas: mental, physical, temporal, effort (mental and physical), frustration, performance, visual, cognitive, and psychomotor (Hart & Staveland, 1988). Participants were asked to evaluate their perceived workload level in these areas on 10-point scales.

The simulator Sickness Questionnaire (appendix C) was used to evaluate participants' simulator sickness symptoms (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The Simulator Sickness Questionnaire consists of a checklist of 16 symptoms. Each symptom is related in terms of degrees of severity (none, slight, moderate, severe). A Total Severity (TS) score can be derived by a weighted scoring procedure and reflects overall discomfort level (Kolasinski, 1995).

A usability questionnaire (appendix D) was constructed, based on the one used in the Unmanned Combat Demonstration (UCD) study, since the test bed used in our study was modeled after the crew station investigated in the UCD study (Kamsickas, 2003). Specifically, the questionnaire included the following sections: MD, reporting (RPT), UV control and status, teleoperation, TA, crew station display and screens, yoke and pedal assembly (YPA), and other equipment. Participants indicated their level of agreement with the items using 7-point numerical scales (strongly disagree [1], disagree [2], somewhat disagree [3], neutral [4], somewhat agree [5], agree [6], and strongly agree [7]). Participants were also given an opportunity to provide comments to support or clarify their numeric responses. The comments, in addition to the numeric responses, provided the researchers with further insight as to the participants' opinions about the crew station.

Finally, a strategy questionnaire was constructed to gain further insights into participants' favorite strategies for using the robotic assets (appendix E).

2.3 Procedure

Fifteen participants were randomly assigned to either the Latency or FR group. Each participant conducted four missions, three with a different robotic asset each, and a final mission with all three robotic assets, as illustrated in table 1. The order of presentation of the single-robot conditions was counterbalanced, while the three-robot (mixed) condition was always the last.

Thus, participants had a chance to complete a mission with each asset singly before conducting a mission with all three.

Participants received training and practice in the tasks they would need to conduct during an initial session that took approximately 3 hours (see appendix A). Participants returned one week later to complete the experiment. Before the experimental session, participants took the Cube Comparison Test (Educational Testing Service, 2005), the scores of which were later used to designate a participant's spatial ability. After the Cube Comparison Test, participants were given some refresher practice and then were asked to complete four route-reconnaissance missions. For each mission, they were given a specific route to travel with the requirement to detect and fire a laser at as many targets as they could find and to reach the end point within 30 minutes. Each mission occurred across the same terrain map but used a different route and direction of travel. Assignment of specific routes to asset conditions was counterbalanced across participants. Each route was approximately 4 km and consisted of an assembly area, a starting point, two checkpoints, and an end point. Participants were instructed to issue a location report at each of these spots. Each mission allowed for the detection of 12 targets, which were a mixture of enemy vehicles and dismounted Soldiers. Upon detection of a target, participants were to send a contact report and fire a laser at the target. Periodically, the warning signal for "Communications Fault" illuminated and the participants needed to double click the button to reset it.

The workload questionnaire (NASA-TLX) and the Simulator Sickness Questionnaire were given at the end of each scenario to assess the participants' perceived workload as well as simulator sickness symptoms. Upon completion of the experimental session, the usability and the strategy questionnaires were given.

In addition to the questionnaire data, mission performance data (such as number of laser firings, number of targets fired upon with a laser, time to complete missions, etc.) were automatically captured by the software.

3. Results

3.1 Task Completion Time

The proportion of participants who finished the mission in the allotted time (30 minutes) was significantly lower in the mixed asset condition, compared with any of the single-asset conditions, Cochran's Q (3 df) = 31.93, $p < .001$. The mean percent of participants completing each mission was at least 89% for all the single-asset conditions but was only 44.8% for the mixed asset condition. Time to complete each mission was also affected by asset condition, $F(3, 51) = 21.18$, $p <.001$. Tukey HSD (Honestly Significant Difference) tests showed that participants took

significantly less time to complete the Teleop condition (M = 17.9 min) than any of the other three conditions. Among these three conditions, participants took significantly less time to complete the UAV condition (M = 23.1 min) than the mixed condition (M = 27.1 min). Time to complete the UGV mission was intermediate to these (M = 24.3 min). Note that participants could not control the speeds of the UAV or UGV, although they could hover the UAV or halt the UGV.

3.2 Target Detection and Acquisition

Table 2 lists several measures relating to target detection and acquisition. When participants detected a target, they were instructed to fire a laser at it; however, sometimes they fired at the same target more than once. Other times, they fired at their own assets by mistake (friendly), and yet other times, they fired at nothing (missed). These data were analyzed with spatial ability scores as a covariate. A mixed analysis of covariance (ANCOVA) with one within-subject factor (Asset) and one between-subject factor (video degradation) and spatial ability as the covariate was performed. The analysis revealed that asset condition (UAV, UGV, Teleop, or Mixed) significantly affected number of targets fired upon, $F(3, 75) = 3.305$, $p < .05$, with Teleop being the lowest (see figure 5). Since the Teleop condition was also completed the most quickly, we examined targets detected per minute. This was also significantly lower in the Teleop condition, $F(2, 50) = 24.80$, $p < .001$, indicating that the fewer targets fired upon in this condition were not simply attributable to the condition's shorter duration. Friendly fires (i.e., firing at the Teleop) were also evaluated. However, the differences were not significant.

Table 2. Target detection and acquisition performance (means and standard deviations).

Measures	UAV	UGV	Teleop	Mixed
Number of targets fired upon (Max = 12)	10.33 (2.02)	9.34 (1.4)	5 (2.03)	9.24 (2.28)
Targets detected per minute*	0.46	0.40	0.27	0.35
Total number of fires	14.63 (4.93)	12.1 (2.61)	8.27 (5.69)	14.66 (5.81)
Number of contact reports	12.17 (4.39)	9.66 (2.11)	8.6 (3.83)	12.07 (3.84)
Number of missed fires	1.8 (2.4)	3 (3.3)	8.97 (7.9)	3.97 (3.41)
Firing at friendly vehicles	.97 (1.79)	.24 (.64)	NA	.38 (.68)

*Computed only for participants who reached the end of the route within 30 minutes.

The detection data for the mixed scenario were segregated by asset type, and a comparison with the single-asset missions is shown in figure 6. There was a significant interaction between asset and number of assets, $F(2, 54) = 22.90$, $p < .001$. In the mixed condition, UAV was used to fire a laser at about the same number of targets as the UAV-alone condition. In contrast, the UGV and the Teleop were used much less frequently in the mixed condition than when they were the sole asset.

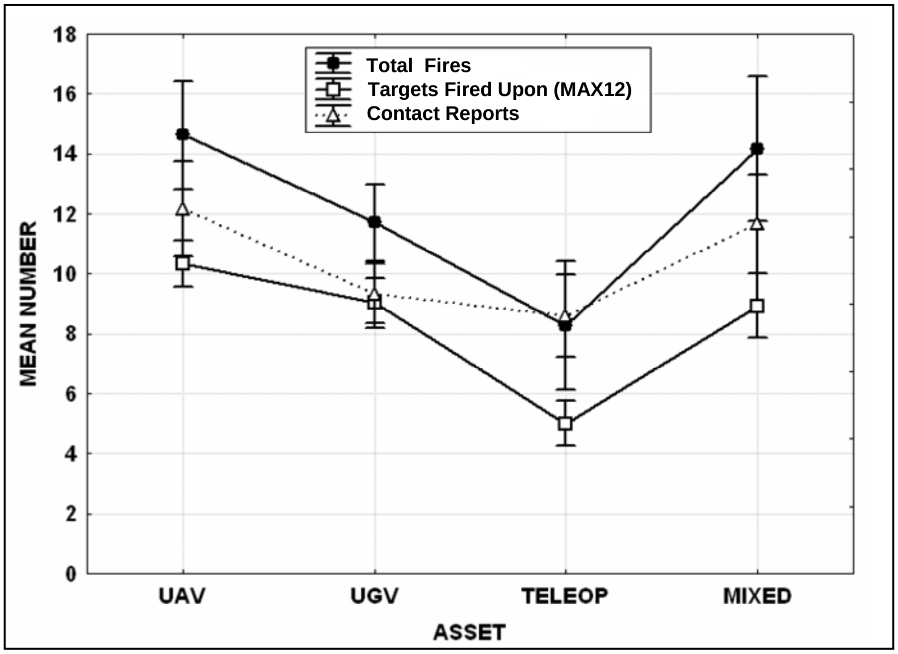

Figure 5. Detection performance.

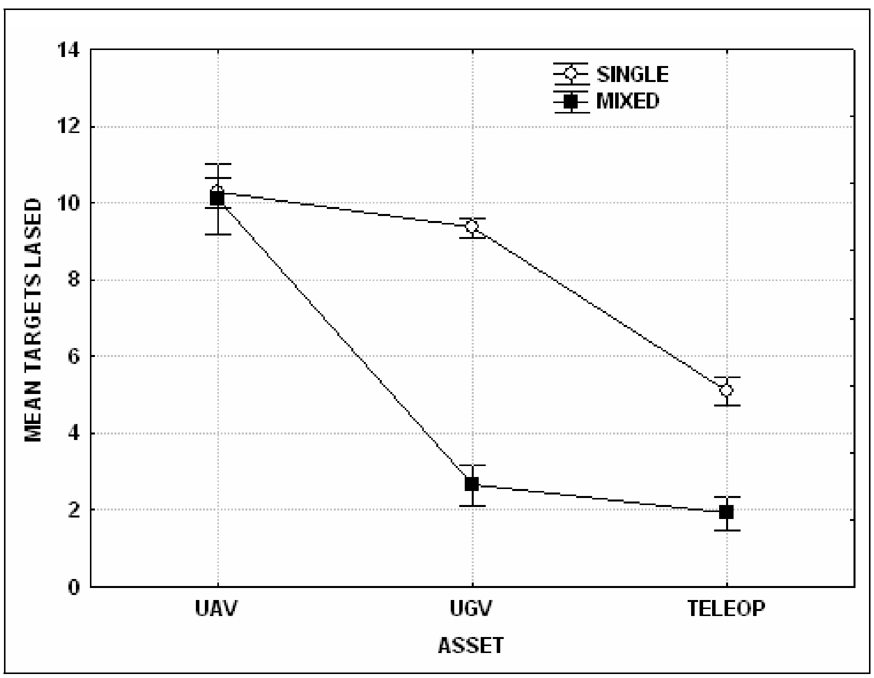

Figure 6. Targets fired upon in single scenarios versus mixed scenario. (Error bars depict standard error of the mean.)

There was no significant effect of latency or FR on the target detection data when the data were analyzed as outlined in the introduction. The effect of latency on the detection data was in the expected direction (poorer firing performance in Group Latency than Group Frame during quarter 1) but failed to be reliable. It is possible that restricting the analysis to only the first

quarter of the Teleop missions limited our power to detect an effect, since there were only three targets to detect.

To evaluate the effect of frame rate, hit rates (number of targets fired upon divided by total firing attempts) for UAV and UGV in the first and last quarters were compared. For the UGV, hit rate was lower in the fourth than the first quarter, and this decrease was greater in Group Frame than Group Latency. For the UAV, hit rate was essentially flat across the quarters. The predicted Group × Quarter interaction failed to be significant when both the UGV and UAV were considered (the Group × Quarter × Asset interaction was not significant).

3.3 Perceived Workload

A mixed analysis of variance (ANOVA) with one within-subject factor (Asset) and two between-subject factors (video condition and gender) demonstrated that participants' self-assessment of workload was significantly affected by Asset condition, $F(3, 54) = 6.437$, $p < .005$. The perceived workload was higher in the mixed condition ($M = 72.3$) than the single-asset conditions (*M's* = 60.9, 61.0, 64.6 for Teleop, UAV, and UGV conditions, respectively). There was a moderately significant interaction for asset, video condition, and gender, $F(3, 54) = 2.628$, $p = .059$. The ratings are graphically presented in figure 7.

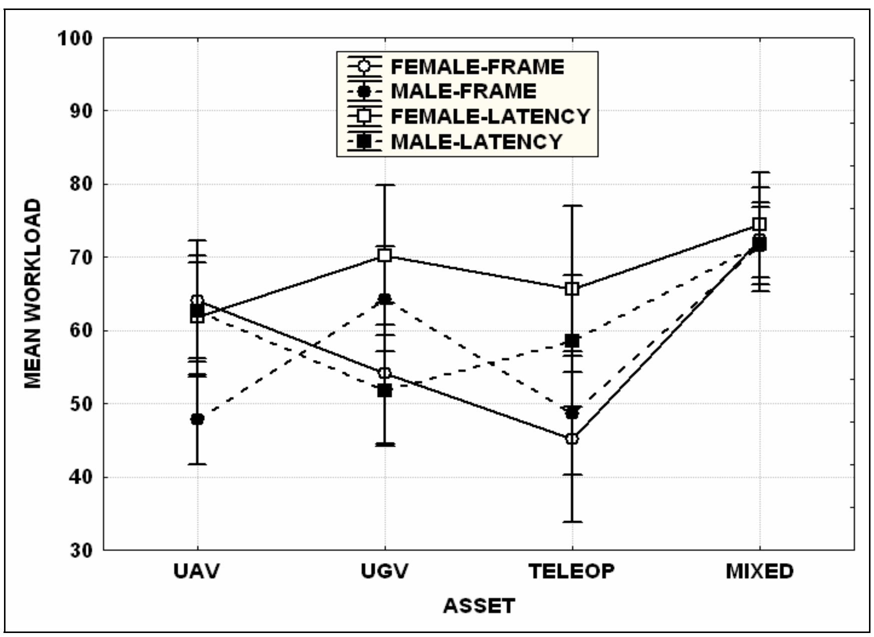

Figure 7. Perceived workload.

3.4 Strategies for Handling Multiple Vehicles

At the end of the mixed asset condition, participants were asked to characterize how they managed the multiple robots by selecting items from the list of choices shown in table 3. More than 75% of the participants indicated that their main strategy was to send the UAV out in front.

The experimenters observed that people tended to search the route with the platform they felt most comfortable with (typically the UAV) and then simply steered the remaining platforms to the end point without doing much additional searching. Thus, there was little evidence that people attempted to coordinate the movement of the platforms or to use them to their best advantage. There were only two "other" responses that implied any deeper thought about how to use multiple assets. These were "If target appeared, I used the most appropriate platform (one with the best view)" and "used the UAV to find Soldiers and the UGV to find tanks."

Table 3. Strategies for managing multiple robotic assets during the mixed scenario.

Options	Percent of participants who selected as a method	Percent of participants who selected as the most dominant method
1. Move one robot from start to finish, and then do the next one, then the last.	10	0
2. Keep UAV in front of the ground robots.	90	75.8
3. Keep Teleop in front of the other robots.	3	0
4. Keep UGV in front of the other robots.	3	0
5. Keep all robots no more than one checkpoint apart.	7	10.3
6. If a target appeared on the map, move the closest robot to view it.	27	3.4
7. If a target appeared on the map, drive the Teleop into position to view it.	4	3.4
8. If a target appeared on the map, fly the UAV to the nearest checkpoint to view it.	43	3.4
9. Other	27	3.4

3.5 Simulator Sickness

The TS score was computed for each participant (see appendix F for the scoring procedure). Participants rated their simulator sickness as the most severe in the Mixed condition (M = 20.82) and the least severe in the Teleop condition (M = 17.67). The mean TS scores for UAV and UGV are 18.08 and 19.95, respectively. A mixed ANOVA with one within-subject factor (Asset) and two between-subjects factors (video condition and gender) was performed. None of the main effects were significant. Generally, a TS score of more than 20 is considered moderate. It appears that our participants experienced more severe simulator sickness when they operated all three robots or when they operated the UGV (whose mean TS score approached 20). Our simulation rarely produced severe symptoms.

3.6 Usability Questionnaire

Twenty-nine participants completed the usability questionnaire, in which participants rated the survey items on 7-point scales, with 7 being "strongly agree" and 1 being "strongly disagree." To evaluate the difference in usability ratings between the two experimental groups, t-tests were conducted. Generally, Latency group participants rated their experiences as less ideal than did the FR group. The Latency group participants felt the pedals were more sensitive to control Teleop's movement than did the FR group; they felt the video imagery for TA from the Teleop

was less clear; the number of displays was less appropriate to accomplish the required tasks; they felt “lost” when working with the crew station more often (table 4). Participants from both FR and Latency groups observed the sensitivity of the yoke and the difficulty of maneuvering it. Some participants from the Latency group commented that it was easy to veer off the road when driving fast. General results of the usability questionnaire and some selected comments from the participants are available in appendix G.

Table 4. Usability survey results.

Statement	Group Latency	Group FR	P value
The pedals were too sensitive to control Teleop’s movement.	$M = 3.33$ ($SD = 1.46$)	$M = 1.84$ ($SD = 1.99$)	$p = .035$
The video imagery for TA from the Teleop is clear.	$M = 4.58$ ($SD = 1.44$)	$M = 6.3$ ($SD = .82$)	$p = .003$
There are not enough displays to accomplish the required tasks.	$M = 2.64$ ($SD = 1.34$)	$M = 1.45$ ($SD = .69$)	$p = .013$
I sometimes feel “lost” when working with the crew station.	$M = 2.96$ ($SD = 1.74$)	$M = 1.73$ ($SD = .79$)	$p = .039$

3.7 Spatial Ability

Participants’ spatial ability was identified by their Cube Comparison Test scores. Spatial ability scores were found to be positively correlated with the number of targets fired upon in the UAV, UGV, and the mixed conditions, $r = .457$, .362, and .502 respectively, all p’s < .05. The correlations between spatial ability and mission completion times were all negative (i.e., participants with higher spatial ability completed their missions faster); however, only the correlation in the UAV condition was significant, $r = -.372$, $p < .05$. The correlation in the Teleop condition was marginally significant, $r = -.301$, $p = .056$.

3.8 Gender Differences

There were no significant gender differences in any of our performance measures, except for the moderately significant difference in the number of contact reports sent by males ($M = 9.847$) and females ($M = 11.675$), $F(1,25) = 3.96$, $p = .058$. Additionally, for firing at friendly vehicles, there was a significant interaction between asset and gender, $F(3, 23) = 3.027$, $p = .05$. Females fired more at friendly vehicles in the mixed condition, while males fired more at friendly vehicles with the UAV. Gender differences in perceived workload and simulator sickness have been presented in previous sections.

4. Discussion

These findings suggest that giving robotic operators additional assets may not be beneficial for enhancing target detection performance. Essentially, participants failed to discover more targets

with three robots, compared with the UAV alone or the UGV alone. Moreover, participants experienced a higher workload in the mixed asset condition, and more than half of participants failed to complete it in the allotted time. It appears that giving multiple assets to robotic operators may be counterproductive. Participants exhibited little natural tendency to coordinate the use of assets.

These findings are consistent with those of other robotic control studies (Dixon et al., 2003; Rehfeld et al., 2005). In Dixon et al., pilots detected fewer targets with two UAVs than with a single UAV. Rehfeld et al. found that giving a second UGV to a single operator or a two-person team failed to enhance the individual's or team's target detection performance. In fact, in difficult scenarios, the single operators actually performed worse with two robots than with one. On the other hand, the two-person teams performed more than twice as well as the one-person condition in those difficult scenarios, regardless of how many assets were used. These findings echoed what have been observed in the field (e.g., using robots for search and rescue efforts in Murphy, 2004) that remote perception is still one of the most fundamental challenges for robotic operators. The findings of Dixon et al., Rehfeld et al., and the current study suggest that, regardless of the types and homogeneity of the robotic platforms, additional assets do not appear to be beneficial for reconnaissance types of tasks, at least when information must be gleaned from streaming video.

Participants did not appear to take advantage of the multiple perspectives available in the mixed asset condition. This might be for several reasons. First, three robots appeared to be more than the operators could handle. Second, participants were not specifically given instructions about how to coordinate multiple assets. Finally, the existing user interface did not support effective integration of sensor information from multiple platforms. An improved user interface should benefit the operator's integration of information from different sources. With the development of the Future Combat System (FCS), one can realistically expect situations when operators need to integrate information from more than one platform, potentially from aerial and ground sources. According to the literature, exocentric frame of reference, which the UAV used, is more suitable for global awareness performance and search tasks than egocentric frame of reference, which the UGV used (McCormick, Wickens, Banks, & Yeh, 1998; Wang, 2004). If an operator has to use a ground robotic vehicle for tasks involving search, some additional information from the exocentric perspective might be beneficial for enhancing the search performance. Salzman, Dede, Loftin, and Ash (1998) showed that a combination of egocentric and exocentric frames of references had benefits for visualization of complex information. However, displays for integrating information from different frames of references (e.g., exocentric and egocentric) present potential human performance issues that need to be carefully evaluated (Thomas & Wickens, 2000). Research has shown that integrating information across egocentric and exocentric views can be challenging for the operator (Olmos, Wickens, & Chudy, 2000). In addition, operators may be susceptible to saliency effects and anchoring heuristic/bias. Salient information on one display may catch most of the operator's attention, and the operator may form an inaccurate judgment because information from the other sources is not properly attended to and integrated. More research in effective ways to present data from multiple

sources and perspectives will provide very useful information to the FCS design efforts. Research programs such as the U.S. Army's HRI Army Technology Objective have started to explore advanced user interface design concepts and innovative technologies to enhance robotic operator performance (Barnes et al., 2005).

Results from our study suggest that the detection performance in the Teleop condition may have been negatively affected by the participants' driving (i.e., Teleop) task. It seems somewhat counterintuitive that participants completed the Teleop mission more quickly than the UAV or UGV missions. Components of the missions included maneuvering, searching the sensor image, firing lasers, and RPT. For the semi-autonomous assets, comparatively little maneuvering was required. It seems that for the Teleop condition, a focus on maneuvering was at the expense of time spent searching. These findings are consistent with Allender and Luck (2005) and Dixon et al. (2003) that robotic operators demonstrated higher SA when the robot's level of automation was higher. Allender and Luck (2005) suggested that the attention on (manual) robotic control might have distracted the operators from focusing on the vehicle's location, which was the study's measure of SA. In Dixon et al., pilots found more targets when their UAV(s) were autonomous than when they were teleoperated.

We were somewhat surprised how little the two types of display degradation affected operator performance. The responses to the usability questionnaire, on the other hand, provided more insight about the differences between the latency and FR conditions. For instance, the Latency group agreed more strongly than the FR group that the pedals were too sensitive to control the Teleop. Given the initial time delay between their input actions and the output responses, participants might have over-compensated and therefore felt that the pedals were "too sensitive." Overall, however, it did not appear that a slow FR at about 5 Hz and a latency of 250 ms had a significant impact on our participants' robotic control and reconnaissance performance.

Our results of superior performance by participants with higher spatial ability using the robotic assets are consistent with past research (e.g., Lathan & Tracey, 2002; Vincow, 1998). Participants with higher spatial ability were found to perform better in both speed and accuracy across platforms. Their superior performance was especially consistent when they used the UAV. Our findings support the recommendation by Lathan and Tracey (2002) that military missions can benefit from the selection of personnel with higher spatial ability to operate robotic devices. Also, training interventions that could enhance the spatial interpretations required might be of benefit (Rodes, Brooks, & Gugerty, 2005).

5. Future Directions

In the ensuing study, we are going to evaluate if gunners in an FCS vehicle such as the Mounted Combat System (MCS) are able to effectively detect targets in their immediate environment

while operating robotic assets in a remote environment. According to Mitchell (2005), which used the Improved Performance Research Integration Tool modeling to examine workload for MCS crew members, the gunner is the only viable option for controlling robotic assets, compared to the other two positions (i.e., commander and driver). In this ensuing study, we are going to simulate the MCS environment and perform an experiment to further examine the workload and performance of the combined position of gunner and robotic operator. Past research in dual task performance suggests that operators may encounter difficulties when both tasks involve focal vision (Horrey & Wickens, 2004). Horrey and Wickens (2004) demonstrated that participants could not effectively detect road hazards while operating in-vehicle devices. Because of the heavy visual load for both the monitoring (i.e., gunner's) task and the robotic control tasks, we expect the gunner/robotic operator will have difficulties in performing both tasks effectively.

6. References

Allender, L.; Luck, J. Latency effects, levels of autonomy, and situation awareness in HRI. Manuscript submitted for publication (copy on file with author), 2005.

Barnes, M. J.; Cosenzo, K. A.; Mitchell, D. K.; Chen, J.Y.C. Soldier robot team as soldier augmentation in future battle spaces: An overview. *Proceedings of the 11th Annual Human-Computer Interaction International Conference*, Las Vegas, NV, 2005.

Darken, R. P.; Kempster, K.; Peterson, B. Effect of streaming video quality of service on spatial comprehension in a reconnaissance task. *Proceedings of the 23rd Army Science Conference* (pp. 391-400), Orlando, FL, 2001.

Dixon, S. R.; Wickens, C. D.; Chang, D. Comparing quantitative model predictions to experimental data in multiple-UAV flight control. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting* (pp. 104-108), Santa Monica, CA, 2003.

Educational Testing Service. *Cube Comparison Test*; Princeton, NJ: ETS, 2005.

Eliot, J. A classification of objects and environmental spatial test. *Perceptual and Motor Skills* **1984**, *59*, 171-174

Ellis, S. R.; Mania, K.; Adelstein, B. D.; Hill, M. (2004). Generalizeability of latency detection in a variety of virtual environments. Retrieved May 28, 2004, from http://www.sussex.ac.uk/Users/km3/hfes.pdf.

Fong, T.; Thorpe, C.; Baur, C. Multi-robot remote driving with collaborative control. *IEEE Transactions on Industrial Electronic* **2003**, *54* (4), 699-704. Retrieved February 23, 2004, from http://vrai-group.epfl.ch/papers/ROMAN01-TF.pdf.

Frank, L. H.; Casali, J. G.; Wierville, W. W. Effects of visual display and motion system delays on operator performance and uneasiness in a driving simulator. *Human Factors* **1988**, *30*, 201-217.

French, J.; Ghirardelli, T. G.; Swoboda, J. The effect of bandwidth on operator control of an unmanned ground vehicle. *Proceedings of the Interservice/Industry Training, Simulation, and Education Conferences (I/ITSEC),* Orlando, FL, 2003.

Gugerty, L. Challenges UAV operators face in maintaining spatial orientation. *Human Factors of UAVs Workshop*, Mesa, AZ. 2004.

Hart, S. G.; Staveland, L. E. Development of NASA TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183); Amsterdam: North-Holland, 1988.

Held, R.; Efstathiou, A.; Greene, M. Adaptation to displaced and delayed visual feedback from the hand. *Journal of Experimental Psychology* **1966**, *72*, 887-891.

Horrey, W. J.; Wickens, C. D. Focal and ambient visual contributions and driver visual scanning in lane keeping and hazard detection. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting* (pp. 2325-2329), Santa Monica, CA, 2004.

Kamsickas, G. *Future combat systems (FCS) concept and technology development (CTD) phase-unmanned combat demonstration-final report*. Technical Report: D786-1006102, Seattle, WA: The Boeing Company, 2003.

Kennedy, R. S.; Berbaum, K. S.; Smith, M. G. Methods for correlating virtual scene elements with simulator sickness incidence. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (pp. 1252-1256), Santa Monica, CA, 1993.

Kennedy, R. S.; Lane, N. E.; Berbaum, K. S.; Lilienthal, M. G. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology* **1993**, *3*, 203-220.

Kolasinski, E. M. *Simulator sickness in virtual environments.* Technical Report 1027, Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences, 1995. Retrieved February 13, 2004, from http://www.hitl.washington.edu/scivw/scivw-ftp/publications/SimSick.rtf.

Lane, J. C.; Carignan, C. R.; Sullivan, B. R.; Akin, D. L.; Hunt, T.; Cohen, R. Effects of time delay on telerobotic control of neutral buoyancy vehicles. *Proceedings of IEEE International Conference on Robotics and Automation*, 2002. Retrieved February 13, 2004, from www.ssl.umd.edu/publications/SSL02-003.pdf.

Lathan, C. E.; Tracey, M. The effects of operator spatial perception and sensory feedback on human-robot teleoperation performance. *Presence* **2002**, *11* (4), 368-377.

MacKenzie, S.; Ware, C. Lag as a determinant of human performance in interactive systems. *Proceedings of ACM Conference on Human Factors in Computing Systems-INTERCHI '93* (pp. 488-493), New York: ACM SIGCHI, 1993. Retrieved May 27, 2004, from http://www.yorku.ca/mack/p488-mackenzie.pdf.

Malcolm, A. A.; Lim, J. S. G. (2003). Teleoperation control for a heavy-duty tracked vehicle. Retrieved June 21, 2004, from http://www.simtech.a-star.edu.sg/Research/TechnicalReports/TR0369.pdf.

Massimino, M.; Sheridan, T. B. Teleoperator performance with varying force and visual feedback. *Human Factors* **1994**, *36,* 145-157.

McCormick, E. P.; Wickens, C. D.; Banks, R.; Yeh, M. Frame of reference effects on scientific visualization subtasks. *Human Factors* **1998**, *40,* 443-451.

McGovern, D. E. (1991). Experience and results in teleoperation of land vehicles. In S. R. Ellis, M. K. Kaiser, & A. C. Grunwald (Eds.), *Pictorial Communication in Virtual and Real Environments* (pp. 182-195). London: Taylor and Francis.

Mitchell, D. K. *Soldier workload analysis of the mounted combat system (MCS) platoon's use of unmanned assets.* ARL-TR-3476, Aberdeen Proving Ground, MD: U.S. Army Research Laboratory, 2005.

Murphy, R. R. Human-robot interaction in rescue robotics. *IEEE Systems, Man and Cybernetics Part C: Applications and Reviews, Special Issue on Human-Robot Interaction* **2004**, 34 (2), 138-153.

Olmos, O.; Wickens, C. D.; Chudy, A. Tactical displays for combat awareness: An examination of dimensionality and frame of reference concepts and the application of cognitive engineering. *International Journal of Aviation Psychology* **2000**, *10* (3), 247-271.

Pausch, R.; Crea, T.; Conway, M. A literature survey for virtual environments: Military flight simulator visual systems and simulator sickness. *Presence* **1992**, *1* (3), 344-363.

Piantanida, T.; Boman D. K.; Gille, J. Human perceptual issues and virtual reality. *Virtual Reality Systems, Application and Research* **1993**, *1* (1), 43-52

Rastogi, A. *Design of an interface for teleoperation in unstructured environments using augmented reality displays* (Master's thesis), 1996. Retrieved August 5, 2004, from http://vered.rose.utoronto.ca/people/anudir/thesis/thesis.html.

Rehfeld, S. A.; Jentsch, F. G.; Curtis, M.; Fincannon, T. Collaborative teamwork with unmanned ground vehicles in military missions. *Proceedings of the 11th Annual Human-Computer Interaction International Conference*, Las Vegas, NV, 2005.

Rodes, W.; Brooks, J.; Gugerty, L. Using verbal protocol analysis and cognitive modeling to understand strategies used for cardinal direction judgments. *Human Factors of UAVs Workshop,* Mesa, AZ, 2005.

Salzman, M.; Dede, C.; Loftin, R. B.; Ash, K. VR's frames of reference: A visualization technique for mastering abstract information spaces. *Proceedings of the Third International Conference on Learning Sciences* (pp. 249-255), Charlottesville, VA: Association for the Advancement of Computers in Education, 1998. Retrieved March 31, 2005, from http://www.virtual.gmu.edu/ss_pdf/icls.pdf.

Schipani, S. P. An evaluation of operator workload during partially-autonomous vehicle operations. *Proceedings of PerMIS 2003.* Retrieved February 23, 2004, from http://www.isd.mel.nist.gov/research_areas/research_engineering/Performance_Metrics/PerMIS_2003/Proceedings/Schipani.pdf.

Sheridan, T. B. *Humans and automation: System design and research issues*. Hoboken, NJ: John Wiley & Son, 2002.

Sheridan, T. B.; Ferrell, W. R. Remote manipulative control with transmission delay. *IEEE Transactions on Human Factors in Electronics* **1963**, *4,* 25-29.

Stanney, K. M.; Mourant, R. R.; Kennedy, R. S. Human factors issues in virtual environments: A review of the literature. *Presence* **1998**, *7,* 327-351. Retrieved April 30, 2004, from http://web.mit.edu/16.459/www/Stanney.pdf

Thomas, L. C.; Wickens, C. D. *Effects of display frames of reference on spatial judgments and change detection.* Technical Report: ARL-00-14/FED-LAB-00-4, Urbana-Champaign, IL: University of Illinois, Institute of Aviation, Aviation Research Laboratory, 2000. Retrieved April 4, 2005, from http://www.humanfactors.uiuc.edu/Reports&PapersPDFs/TechReport/00-14.pdf.

Van Erp, J. B. F.; Padmos, P. Image parameters for driving with indirect viewing systems. *Ergonomics* **2003**, *46,* 1471-1499.

Vincow, M. A. *Frame of reference and navigation through document visualizations.* Unpublished doctoral dissertation, University of Illinois at Urbana-Champaign, 1998.

Wang, W. *Human navigation performance using 6 degree of freedom dynamic viewpoint tethering in virtural environments.* Unpublished doctoral dissertation, University of Toronoto, Canada, 2004. Retrieved March 30, 2005, from http://vered.rose.utoronto.ca/people/wenbi/dissertation/.

Watson, B.; Walker, N.; Ribarsky, W.; Spaulding, V. Effects of variation in system responsiveness on user performance in virtual environments. *Human Factors* **1998***, 40*, 403-414.

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Appendix A. Demographic Questionnaire

Participant # _______ Age ______ Major ________________ Date ___________ Gender ___

1. What is the highest level of education you have had?
Less than 4 yrs of college ____ Completed 4 yrs of college ____ Other ____

2. When did you use computers in your education? (*Circle all that apply*)

Grade School	Jr. High	High School
Technical School	College	Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

Home Work Library Other________ Do Not Use

4. For each of the following questions, circle the response that best describes you.

How often do you:	
Use a mouse?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a joystick?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a touch screen?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use icon-based programs/software?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use programs/software with pull-down menus?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use graphics/drawing features in software packages?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use E-mail?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Operate a radio controlled vehicle (car, boat, or plane)?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Play computer/video games?	Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computer? (check √ one)
_____ Novice
_____ Good with one type of software package (such as word processing or slides)
_____ Good with several software packages
_____ Can program in one language and use several software packages
_____ Can program in several languages and use several software packages

7. Are you in your usual state of health physically? YES NO
If NO, please briefly explain:

8. How many hours of sleep did you get last night? ______ hours

9. Do you have normal color vision? YES NO

10. Do you have prior military service? YES NO If Yes, how long __________

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Appendix B. NASA-TLX Questionnaire

Please rate your overall impression of demands imposed on you during the exercise.

1. Mental Demand: How much mental and perceptual activity was required (e.g., thinking, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

2. Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

3. Temporal Demand: How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

4. Level of Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

5. Level of Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

6. Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

7. Please mark the indicated loading that most closely matches the work performed by your visual, cognitive, and motor efforts on the task just completed.

Visual LOW Load |---|---|---|---|---|---|---|---|---|---| HIGH Load
1 2 3 4 5 6 7 8 9 10

Cognitive LOW Load |---|---|---|---|---|---|---|---|---|---| HIGH Load
1 2 3 4 5 6 7 8 9 10

Psychomotor (Relating to the physical activities associated with mental processes

LOW Load |---|---|---|---|---|---|---|---|---|---| HIGH Load
1 2 3 4 5 6 7 8 9 10

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Appendix C. Simulator Sickness (Current Health Status) Questionnaire

ID________________ Time & Date

Instructions: Please indicate how you feel **right now** in the following areas, by **circling** the word that applies.

1.	General Discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Headache	None	Slight	Moderate	Severe
4.	Eye Strain	None	Slight	Moderate	Severe
5.	Difficulty Focusing	None	Slight	Moderate	Severe
6.	Increased Salivation	None	Slight	Moderate	Severe
7.	Sweating	None	Slight	Moderate	Severe
8.	Nausea	None	Slight	Moderate	Severe
9.	Difficulty Concentrating	None	Slight	Moderate	Severe
10.	Fullness of Head	None	Slight	Moderate	Severe
11.	Blurred vision	None	Slight	Moderate	Severe
12.	Dizzy (Eyes Open)	None	Slight	Moderate	Severe
13.	Dizzy (Eyes Closed)	None	Slight	Moderate	Severe
14.	Vertigo*	None	Slight	Moderate	Severe
15.	Stomach Awareness**	None	Slight	Moderate	Severe
16.	Burping	None	Slight	Moderate	Severe

*Vertigo is a disordered state in which the person or his/her surroundings seem to whirl dizzily: giddiness.
** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Are there any other symptoms you are experiencing right now? If so, please describe the symptom(s) and rate its/their severity below. Use the other side if necessary.

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Appendix D. Usability Survey

Instructions

This questionnaire is designed to elicit your reactions for the use of the crewstation. Your responses will help us understand what aspects of the crewstation you find inefficient or difficult to use. This questionnaire provides an opportunity to evaluate the usability of the system. We will use your responses to influence the design of the future crewstation. To as great a degree as possible, think about all the tasks that you have performed with the crewstation while you answer the questions.

Read each statement or question and indicate your response to the statement or question by circling the value you feel best gauges your answer to the question on the scale underneath it. If a statement does not apply, circle **N/A**. Use the space on the right to provide any comments that would help us improve the design of the crewstation interface. Comments clarifying answers are extremely useful.

Map Display

Comments

1. **I used the Mapping display often.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

2. **The button labels accurately represented the buttons' functionality.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

3. **The information presented on the mapping display was easy to read.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

4. **The map resolution made it difficult for me to select a specific location.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

5. **It was easy to understand what the icons used on the map displays represented.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

6. **I was able to control map graphics effectively.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

7. **Icons representing different ARVs were easy to distinguish.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

8. **The icons that represent ARVs are too large.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

9. **Geographic orientation of the map terrain features makes sense.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

10. **The map terrain features (roads, water, vegetation) were difficult to see.** Comments
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

11. **The resolution of the location grid lines was sufficient to allow me to accomplish my goals.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

12. **The symbols that were used did <u>not</u> make sense.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

13. **The orientation of the ARVs is represented clearly.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

14. **The icons that represent non-ARV units are too small.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

15. **I would like a way to customize the background colors on the map.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

16. **The map was my main source of situation awareness.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

17. **Text on the map status display was easy to understand.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

18. **It would have been helpful to have more information presented on the map display.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

19. **I used the cursor center function often.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

20. Overall the mapping display was easy to use.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

Reporting

1. The button labels accurately represented the buttons' functionality. Comments
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

2. Much of the information presented on the display was NOT helpful. Comments
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

3. I sometimes felt 'lost' navigating the reporting display screens.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

4. Composing a SITREP was an easy task to accomplish.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

5. Composing a SITREP took too long to accomplish.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

6. The entry fields for composing a SITREP were found in the order I expected them to be.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

7. There was not enough information displayed on the reporting screen.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

8. Composing a SPOT report was an easy task to accomplish.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

9. Composing a SPOT report took too long to accomplish.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

10. The entry fields for composing a SPOT report were found in the order I expected them to be.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

11. Using the reporting display to compose reports was an easy process overall.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

Unmanned Vehicle Control & Status

1. I used the unmanned vehicle (UV) status display often. Comments

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

2. There was adequate information displayed with regard to the state of the UVs.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

3. The text on the UV detailed information screen was easy to read. Comments

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

4. The information presented in the display was easy to interpret.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

5. The colors used to indicate the status of various UV resources (ammo, fuel, etc.) made sense.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

6. Requesting control of an UV was easy to do.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

7. The button labels accurately represented the buttons' functionality.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

8. The icons used to depict UV resources (fuel, communication status, ammo, etc.) and the state of the resources was easy to interpret.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

9. The UV control display was easy to use.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

Teleoperation

Comments

1. **I used the teleoperation display often.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

2. **The yoke made it difficult to control the ARVs.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

3. **The pedals were too sensitive to control ARV movement.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

4. **The print/ text presented on the teleoperation display was easy to read.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

Comments

5. **The yoke was too sensitive to control ARV direction.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

6. **The video update rate was sufficient to teleoperate the ARV at high speed.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

7. **The video update rate was sufficient to teleoperate the ARV at low speed.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

8. **The streaming video was sufficient to allow me to teleoperate the ARV.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

9. **The teleoperation display did <u>not</u> provide enough information (speed, direction, etc.) on ARV status.**
   Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
   1 2 3 4 5 6 7

10. **I used the map display while teleoperating an ARV to help me maintain the location of an ARV.**
    Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
    1 2 3 4 5 6 7

11. **There was a significant time delay that made controlling the ARV difficult.**
    Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
    1 2 3 4 5 6 7

12. **The Teleoperation display provided too much information (speed, direction, etc.) on ARV status.**
    Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
    1 2 3 4 5 6 7

13. The backup feature was very useful when an ARV got stuck.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

14. I had to teleoperate the ARV often.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

15. The button labels accurately represented the buttons' functionality.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

16. I found the Teleoperation display easy to use to control ARVs.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

Target Acquisition

Comments

1. I used the Target Acquisition (TA) display often.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

2. The print/text used on the TA display was easy to read.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

3. The layout of the TA screen made sense.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

4. The video imagery for TA from the ARVs is clear.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

5. The information presented on the TA screen is <u>not</u> helpful.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

6. The TA display should contain additional information.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

7. The orientation of the icons (ARV gun direction) presented on the display made sense.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

8. The aiming reticule was easy to use.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

9. The button labels accurately represented their intended functions.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

10. **It was easy to select an ARV to engage a target.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

11. **I would like to see more functionality added to the *Target Acquisition* display.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

12. **There is <u>not</u> enough information presented on the TA screen.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

13. **This display made it easy to engage targets.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

General Usability

I. Crewstation Display and Screens.

Definitions:

- A **screen** is defined as the physical object that may be handled.
- A **display** is the software image that is displayed on the screen.
- A **hard button** is a physical button on the track ball.
- A **soft button** is a computer-generated image of a button displayed on the screen

Comments

1. **The touchscreen buttons were large enough to use effectively.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

2. **The print/ text on the crewstation soft buttons was clear, and easy to read.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

3. **The point at which my finger touches is not identical to the point indicated by the touchscreen (there are parallax problems).**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

4. **The layout of the hard buttons made sense.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

5. The layout of the hard buttons made sense.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

6. It is hard to select small items when using the touchscreen.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

7. The number of displays is appropriate to accomplish the required tasks.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

8. I had trouble selecting the appropriate display to use.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

9. I frequently made errors in selecting the correct display to use when attempting to accomplish a task.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

10. There are <u>not</u> enough displays to accomplish the required tasks.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

Comments

11. **I preferred using the touchscreen to the trackball for interacting with the displays.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

12. **It was easy to learn to use the basic features of the crewstation.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

13. **Frequently, <u>inadvertent</u> contact with the touchscreen causes functions to activate unintentionally.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

14. **Throughout the crewstation, the same terminology is used to indicate the same information.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

15. **I sometimes feel "lost" when working with the crewstation.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

16. **I had a hard time finding information I needed on the crewstation.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

17. **The crewstation presents system messages in a consistent format and location.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

18. **It was easy to understand what the icons used on the crewstation displays represented.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

19. **The crewstation responds too slowly.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

20. **The crewstation keeps me informed about what it is doing.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

21. **The messages that appear on the crewstation display are hard to understand.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

22. The crewstation gives appropriate warning messages when I am about to make a serious mistake.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

23. With the crewstation, if I make a mistake I can correct it easily. Comments

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

24. It is obvious which command button brings up the crewstation display I need next.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

25. It was difficult to select a specific control on the crewstation touch screen.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

26. Information is appropriately arranged on the crewstation displays.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

27. Color-coding on the crewstation displays is helpful.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

28. The symbols that were used were hard to learn.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

29. Overall, I think the crewstation was easy to learn.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

30. Overall, I think the crewstation was easy to work with.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

II. Yoke and Pedal Assembly.

1. The buttons on the yoke were easy to use. Comments

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

2. There were too many buttons on the yoke to choose from.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

3. The bump cursor was easier to use than the buttons on the screen.

Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

4. **I used the bump cursor to navigate the buttons on the displays frequently.** Comments
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

5. **The yoke was too sensitive to over-steer.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

6. **It was easy to slew too the target using the yoke.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

7. **It was easy to maintain crosshairs on the target with the yoke.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

III. Other Equipment.

1. **I used the keyboard often throughout the scenario.** Comments
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

2. **I used the trackball often throughout the scenario.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

3. **The keyboard was in a position that was easily accessible.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

4. **It was easy to adjust the positioning of hardware (seat, yoke placement, screens, etc.) in the crewstation.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

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Appendix E. Strategy Questionnaire

Which of the following describes the method you used on the last scenario, when you had all three robots to control? (Check all that apply)

- ❑ 1. Move one robot from start to finish, and then do the next one, then the last.
- ❑ 2. Keep the UAV in front of the ground robots.
- ❑ 3. Keep the Teleop in front of the other robots.
- ❑ 4. Keep the UGV in front of the other robots.
- ❑ 5. Keep all robots no more than one checkpoint apart.
- ❑ 6. If a target appeared on the map, move the closest robot to view it.
- ❑ 7. If a target appeared on the map, drive the Teleop into position to view it.
- ❑ 8. If a target appeared on the map, fly the UAV to the nearest checkpoint to view it.
- ❑ 9. Other (describe)

Of the answers above that you checked, please rank order the strategies from most important to least important.

Please estimate the number of targets you acquired with each vehicle.

UAV_____.
UGV______.
Teleop____.

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Appendix F. Scoring Procedure for the Simulator Sickness Questionnaire

Symptoms scored 0 (None) - 3 (Severe)

Nausea - Sum of General discomfort, increased salivation, sweating, nausea, diff concentrating, stomach awareness, burping

Oculomotor - Sum of general discomfort, fatigue, headache, eye strain, diff focusing, diff concentrating, blurred vision

Disorientation - Sum of diff focusing, nausea, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes closed), vertigo

Total Severity Score = (Nausea + Oculomotor + Disorientation) x 3.74

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Appendix G. General Results of the Usability Questionnaire and Selected Comments from Participants

I. General Results of the Usability Questionnaire.

The following sections address other general results of the usability questionnaire, focusing on items in which the modal response reflected the opinions of nearly half of the respondents.

Map Display (MD). Of the 20 MD items, there were 3 in which almost half of the respondents were in agreement. The statement for MD item number 2 (MD2) was "The button labels accurately represented the buttons' functionality." Fourteen participants (across conditions) agreed with the statement. For MD2, the range of responses for the middle 50% of participants in the FR condition was 5-6, as compared to the range for the middle 50% of participants in the latency condition, which was 5-7. The statement for MD5 was "It was easy to understand what the icons used on the map displays represented." Although the range for this item was 1-7, the modal response was 6; and, the frequency of the mode was 14. This indicates that these 14 participants all agreed with the statement. Everyone in the middle 50% of the latency condition selected 6 as their response. For the FR condition, however, the range for the middle 50% was 5-6. Map display item 12, which read, "The symbols that were used did not make sense," resulted in 14 out of 29 participants disagreeing with the statement. The range of responses for the middle 50% of each condition was 1-2.

Reporting (RPT). Item 4 of the RPT section garnered strong agreement from 14 out of the 29 participants. This item read, "Composing a SITREP was an easy task to accomplish." Even though the range of responses for the middle 50% of the latency group was 5-7, whereas that for the middle 50% of the frame group was 6-7, overall this suggests agreement with the statement. Despite this agreement, participant comments provided insight into some of the problems with composing a SITREP. Participants commented, "easy, but took too long" and "The difficulty lies within the timing of the reporting."

Unmanned Vehicle Control and Status (UVCS). The statement for UVCS6 was, "Requesting control of a UV was easy to do." The modal response for this item was seven, indicating strong agreement with the statement (across conditions). Participant comments to clarify the responses were, "Sometimes it would stall or take a long delay" and "…once steps were learned."

Teleoperation (TELE). Item 11 of the teleoperation section of the questionnaire stated, "There was a significant time delay that made controlling the armed reconnaissance vehicle (ARV) difficult." Fourteen participants disagreed with this statement. Everyone in the middle 50% of the Latency group selected 2 as their response, whereas the response range for the middle 50% of the Frame group was 2-3. This suggests overall disagreement with the statement. One

participant from the latency condition commented, “I would veer off path, but that was due to speed.”

Target Acquisition (TA). There was only one item in which almost half of the participants (13 out of 29) responded in agreement with one another. That item was TA9, which stated, “The button labels accurately represented their intended functions.” The participants agreed with this statement. For one particular TA item, TA8, there were multiple modal responses; however, the participants’ comments provide considerable information. The item read, “The aiming reticule was easy to use.” The participant comments were, “should be a dot or +, not an open space with lines on the outside of it,” “hard to maneuver crosshairs with UAV and UGV,” “finer tuning should be option instead of aiming next [to], below target,” “too sensitive because depressing the palm grips reduces motor functions of tester.”

Crew Display and Screens (CDS). Fourteen of 29 participants agreed with the statement for CDS26, which read, “Color coding on the crewstation displays is helpful.” One participant, however, commented, “not much color coding used.”

Yoke and Pedal Assembly (YPA). The statement for Item 2 of the YPA section read, “The buttons on the yoke were in locations that are easy to reach.” Fifteen out of 29 participants strongly agreed with this statement. However, one participant commented, “The yoke was far away from me (seat couldn’t move up more).”

II. Selected Comments on Usability from Participants. (Note: Item numbers do not match those in the survey)

Map Display

1. I used the Mapping display often.

“If I saw a bad guy on the map, it was hard to find him with the UAV. It was like I was looking at two different screen maps.”

2. It was easy to understand what the icons used on the map displays represented.

“Sometimes I would confuse the UAV/UGV.”

“Vehicle icons were not distinctive enough for quick recognition w/ large scale incoherent (multiple vehicles)”

3. Icons representing different ARVs were easy to distinguish.

“Sometimes I would confuse the UAV/UGV.”

“a little difficult to tell which was which without moving vehicles”

“couldn't tell the difference between it and tank “

4. Geographic orientation of the map terrain features makes sense.

“more color for topography switch between visual/topographical/graphic control/road/tactical to filter out unnecessary input”

5. The orientation of the ARVs is represented clearly.

“used compasses”

“could differentiate back and front of teleoperation by field of view icon.”

“hard to tell where they are facing”

6. I would like a way to customize the background colors on the map.

“It's easier to learn one consistent format.”

“more color for topography switch between visual/topographical/graphic control/road/tactical to filter out unnecessary input”

7. **The map was my main source of situation awareness.**

"used compass more to gauge and map to confirm direction"

8. **It would have been helpful to have more information presented on the map display.**

"Topographical info like elevation from sea level of different geographical areas"
"more color for topography switch between visual/topographical/graphic control/road/tactical to filter out unnecessary input"

9. **Overall the mapping display was easy to use.**

"Use of a trackball in a touch screen interface was backwards, counterproductive. At least a touch-pad to coordinate mental functions if not fully touch screen integrated map interface"

Reporting

1. **I sometimes felt 'lost' navigating the reporting display screens.**

"It would be nice to have larger buttons that showed the nav tree better (previous choices stay) "

Unmanned Vehicle Control & Status

1. **The UV control display was easy to use.**

"should have a joystick for UAV"

Teleoperation

1. **The yoke made it difficult to control the ARVs.**

"too sensitive for turret" (Latency group)

2. **The yoke was too sensitive to control ARV direction.**

"a little bit too sensitive" (FR group)

3. **The video update rate was sufficient to teleoperate the ARV at high speed.**

"could not go faster than 20 without losing control" (Latency group)

4. **There was a significant time delay that made controlling the ARV difficult.**

"I would veer off path, but that was due to speed." (Latency group)

Target Acquisition

1. **The TA display should contain additional information.**

"better direction indicates when switching between ARVs"
"Target info"

2. **The aiming reticule was easy to use.**

"should be a dot or +, not an open space with lines on the outside of it"
"hard to maneuver crosshairs with UAV and UGV" (FR group)
"Finer tuning should be option instead of aiming next, below target"
"too sensitive because depressing the palm grips reduces motor functions of tester" (Latency group)

General Usability

I. Crewstation Display and Screens.

1. The touchscreen buttons were large enough to use effectively.

"The mission status screen was too small."
"Did not respond well to a quick change"
"These buttons were hard to use effectively"
"not when it came to scrolling lists"
"except scroll button"

2. The point at which my finger touches is not identical to the point indicated by the touchscreen (there are parallax problems).

"only with the scroll menu" (Latency group)
"Only on the scrollbars" (Latency group)

3. I preferred using the touchscreen to the trackball for interacting with the displays.

"the track ball was more precise and easy, but touchscreen would be better if worked better"
"trackball is unwieldy when trying to act and react quickly"

4. The crewstation presents system messages in a consistent format and location.

ıformation was not centralized"

5. Overall, I think the crewstation was easy to work with.

"except the map w/ trackball that was 'backwards' and frustrating"

II. Yoke and Pedal Assembly.

1. The buttons on the yoke were easy to use.

ιcept palm grips for turret control"

2. The yoke was too sensitive to over-steer.

"somewhat sensitive" (FR group)
"at high speeds, yes" (Latency group)

3. It was easy to slew to the target using the yoke.

"a little difficult to place cursor dead on" (Latency group)

4. It was easy to maintain crosshairs on the target with the yoke.

"need more fine tuning capabilities" (FR group)
"too sensitive because my hands had to squeeze the palm grips; this reduced my overall hand coordination" (Latency group)

Glossary of Acronyms

ARV	armed reconnaissance vehicle
CDS	crew display and screens
ECATT-MR	Embedded Combined Arms Team training and mission rehearsal
FCS	Future Combat System
HRI	human-robot interaction
ID	identification
MCS	Mounted Combat System
MD	map display
OCS	operator control station
OneSAF	semi-automated forces
RDECOM	Research, Engineering, and Development Command
RPT	reporting
SA	situational awareness
TA	target acquisition
TS	total severity
UAV	unmanned aerial vehicle
UCD	unmanned combat demonstration
UGV	unmanned ground vehicle
UV	unmanned vehicle
YPA	yoke and pedal assembly

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